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The guideline recommends air quality modeling techniques that may be applied to air pollution control strategy evaluations and new source reviews, including prevention of significant deterioration. It is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, by State and local agencies, and by industry and its consultants. It also identifies modeling techniques and data bases that EPA considers acceptable. The guideline makes specific recommendations concerning air quality models, data bases, and general requirements for concentration estimates.

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Office of Air and Waste Management
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OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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Preface

In late 1976 it became clear from needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by deliberations of Congress that greater consistency in the use of air quality models is needed. Consistency is required so that air pollution control agencies, industry and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits.

To meet this need, EPA undertook a series of steps that would lead to a widely reviewed guide on the use of air quality models. After initial opinions from EPA's Regional Offices were received, the Office of Air Quality Planning and Standards prepared a draft guide. This guide was submitted for critical review to a conference of specialists.* The individual conferees were widely recognized experts in the development and use of air quality models. Based on the judgments and suggestions of the conferees, the guide was revised and presented for public comment at meetings** in Atlanta, Chicago, Denver, New York and San Francisco. These meetings were attended by approximately 500 representatives of control agencies, industry, environmental groups and the scientific community. These attendees submitted extensive oral and written comments which were evaluated and considered in the preparation of this guide.

During the development of the guide, the Clean Air Act Amendments of 1977 were signed into law. These Amendments required EPA to conduct a Conference on Air Quality Modeling*** with special attention given to models applicable to prevention of significant deterioration. That Conference was held in Washington, D. C. on December 14-15, 1977, with the "Interim Guideline on Air Quality Models" (October, 1977) serving as the focal point. The Conference was attended by over 300 individuals with similar backgrounds and interests to those who participated in the five previous meetings. A verbatim transcript of the proceedings was maintained and written comments were accepted. Those comments and suggestions were considered in this revision to the guide.

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*Roberts, J. J., Ed. "Report to the U. S. EPA of the Specialists' Conference on the EPA Modeling Guidelines." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February, 1977.

**Slater, H. H., Chairman. "Comments and Recommendations Concerning the Draft Guidelines on Air Quality Models." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May/June, 1977.

***Environmental Protection Agency. "Conference on Air Quality Modeling." Acme Reporting Company, Washington, D. C. 20005, December, 1977.

The Clean Air Act Amendments also required the promulgation of regulations which specify air quality models to be used in analyses pertinent to prevention of significant deterioration. The guide is included by reference in 40 CFR 52.21 regulations concerning significant deterioration. The models discussed here are those recommended for use in PSD analyses.

Due to the continuing development of a wide variety of air quality models and numerous gaps in our ability to simulate atmospheric dispersion processes, EPA plans to review and update this guide periodically. EPA is also actively pursuing mechanisms by which (1) the technical community can take an active role in such reviews and updates and (2) a wider range of models, including those developed by groups other than EPA, can be incorporated. EPA and other groups within the technical community have ongoing programs in the areas of complex terrain, long range transport, fugitive dust, turbulence characterization, and model validation/improvement. It is anticipated that within about 18 months outputs which have practical applications will have resulted from these various programs. Thus EPA expects that further revision to this guide will be appropriate at that time. In the future, it appears that reviews and updates of this guide at 18-24 month intervals are also appropriate. These revisions will be synchronized with Conferences on Air Quality Modeling which EPA is required to conduct at least every three years.

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1.0 INTRODUCTION

The purpose of this guide is to recommend air quality modeling techniques that may be applied to air pollution control strategy evaluations and to new source reviews, including prevention of significant deterioration. It is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, by State and local agencies and by industry and its consultants. It is appropriate for use by other Federal agencies with environmental impact statement and land management responsibilities. Similarly, it serves to identify for all interested parties those techniques and data bases that EPA considers acceptable. The guide is not intended to be a compendium of modeling techniques. Rather it should serve as a basis by which air quality managers, supported by sound scientific judgment, have a common measure of acceptable technical analyses.

This guide makes specific recommendations concerning (1) air quality models, (2) data bases and (3) general requirements for concentration estimates. It should be followed in all evaluations relative to State Implementation Plans (SIPs). However, it may be found that (1) the recommended air quality model is not appropriate for a particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other data, models and techniques deemed appropriate by the Regional Administrator may be used. Thus, even though specific recommendations are made, they should not be considered rigid requirements. The preferred model is that which best

simulates atmospheric transport and dispersion in the area of interest. However, deviations from this guide should be fully supported and documented.

The contents of this guide are summarized in Figure 1. The basic steps in applying an air quality model to a practical situation, and the necessary data bases and information, are shown. The numbers in parentheses refer to specific sections of the guide.

As indicated in Figure 1, it is generally advisable to first apply a model requiring a minimum expenditure of resources (i.e., a preliminary screening technique). The purpose of a screening technique is to single out, with minimum effort, those sources that clearly will not cause or contribute to ambient concentrations in excess of the National Ambient Air Quality Standards (NAAQS) or allowable concentration increments. In doing so, unwarranted expenditure of resources (a refined analysis when a simple approach would suffice) can be avoided. Another advantage of first applying a relatively simple model is to obtain concentration estimates or receptor information that can be helpful in a more refined analysis.

If the screening analysis indicates that the source may pose an air quality problem, application of a relatively sophisticated model is then warranted for obtaining more refined concentration estimates. The selection of an appropriate model should be based upon all the factors indicated in Figure 1. Of particular importance are the source and meteorological data used in the application.

Given the selection of a refined air quality model, an appropriate receptor field must be designated. The model can then be applied giving

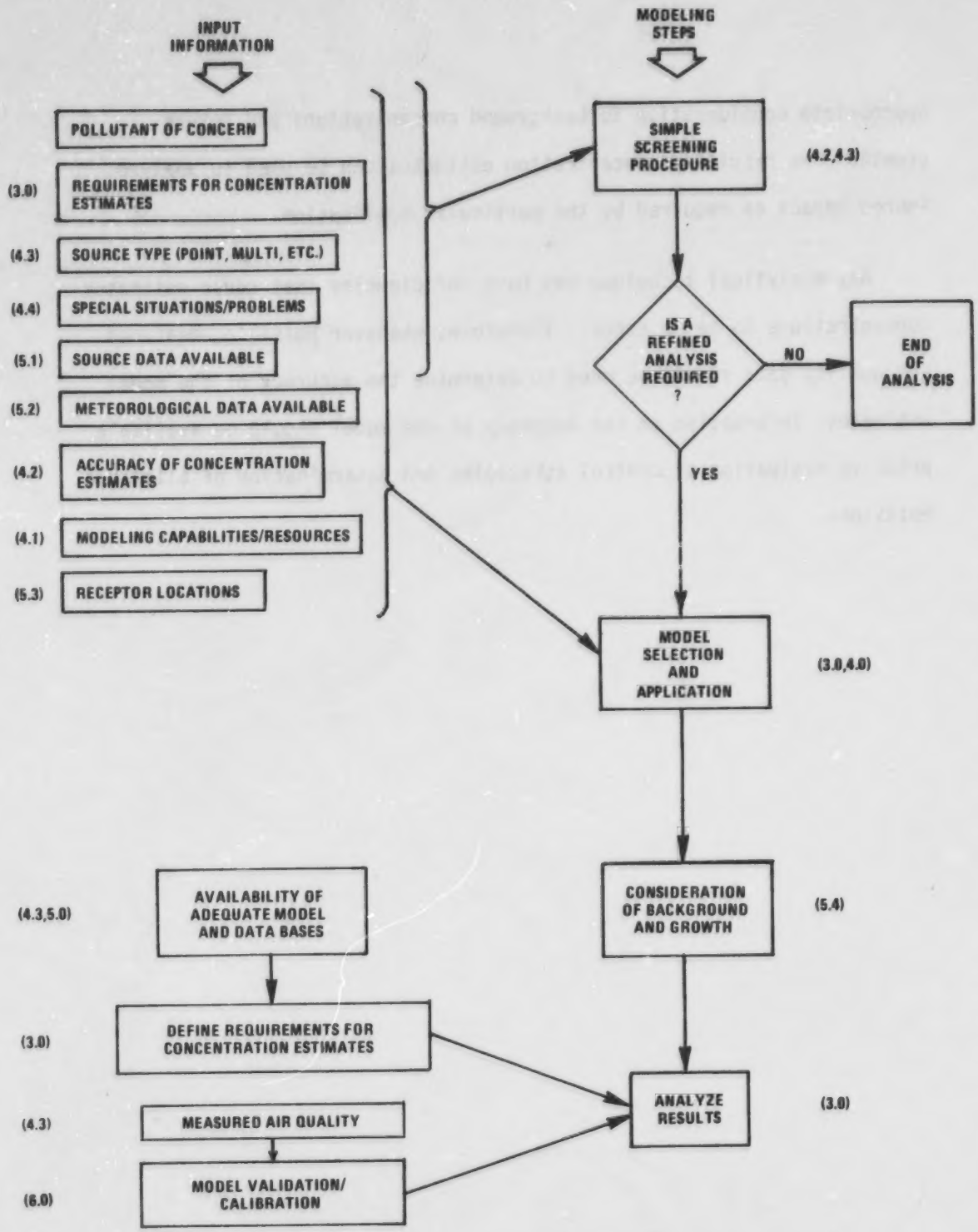

Figure 1. Selection and application of air quality models and data bases. (Applicable sections of the guideline are indicated in parentheses.)

appropriate consideration to background concentrations and future growth. The resulting concentration estimates can be used to analyze source impact as required by the particular application.

Any analytical technique may have deficiencies that cause estimated concentrations to be in error. Therefore, whenever possible, measured air quality data should be used to determine the accuracy of the model estimates. Information on the accuracy of the model should be available prior to evaluation of control strategies and determination of allowable emissions.

2.0 OVERVIEW

Air quality models have been widely used to identify potential violations of the National Ambient Air Quality Standards (NAAQS) and to determine emission limits. The need for air quality models in the development and revision of SIP-related control strategies was identified very early.[1] However, due to the initial demands of the Clean Air Act (1970) on available resources, it has not generally been possible to use air quality models to the extent desired. Thus, many SIPs are based on an example region concept, a simple emissions rollback model and available measurements of air quality. In recent years, however, air quality models have been more widely used. As these models and associated data bases increase in sophistication, they allow more precision in estimating concentrations and in assessing the adequacy of control strategies.

In addition to their use in development and revision of control strategies, air quality models are also required in the New Source Review program to insure attainment and maintenance of NAAQS, and to prevent significant air quality deterioration. Judgments must be made concerning allowable emission rates and the placement of new sources that may cause specific air quality levels to be exceeded or that may contribute significantly to existing violations.

It must be noted that EPA has never encouraged the use of air quality models in place of measured data. In fact, EPA encourages the use of measured data in evaluating the effectiveness of control strategies and in determining emission limits. The two should be used in a complementary manner whenever possible. The air quality data can be especially useful in validating air quality models and thus have a direct impact on

the air quality assessment. However, in some cases, the source does not yet exist or there are insufficient air quality data to evaluate the spatial distribution of concentrations and the impact of control strategies. Thus, the use of models as the primary analytical tool is unavoidable.

In the use of models it would be advantageous to categorize the various control programs and to apply a designated model to each proposed source which comes under a given program. However, the diversity of the nation's topography and climate, and variations in source configurations and operating characteristics dictate against a routine "cookbook" analysis. There is no single model capable of properly addressing all conceivable situations. Meteorological phenomena associated with threats to air quality standards are rarely amenable to simple mathematical treatment. Any modeling effort should be directed by highly competent individuals with a broad range of experience and knowlege in air pollution meteorology and coordinated closely with specialists in emissions characteristics and data processing. The judgment of well-trained professional analysts is essential.

Nevertheless, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by the deliberations of Congress[2] that greater consistency in the use of models and data bases is in order. Consistency is required so that air pollution control agencies and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. This guide promotes the required consistency.

3.0 REQUIREMENTS FOR CONCENTRATION ESTIMATES

Specific air quality standards and increments of pollutant concentrations must be considered for control strategy evaluations and for new source reviews, including prevention of significant deterioration. This section specifies general requirements for concentration estimates and identifies the relationship between emission limits and air quality standards/increments for these applications.

3.1 Control Strategy Evaluations

SIP-related emission limits should be based on concentration estimates for the averaging time which results in the most stringent control requirements. In all cases these concentration estimates are assumed to be a sum of the concentration contributed by the source and an appropriate background concentration (see pp. 36-39).

If the annual average air quality standard is exceeded by a greater degree (percentage) than standards for other averaging times, the annual average is considered the restrictive standard. In this case the sum of the highest estimated annual average concentration and the annual average background provides the concentration which should be used to specify emission limits. However, if a short-term standard is exceeded by a greater degree and is thus identified as the restrictive standard, other considerations are required because the frequency of occurrence must also be taken into account.

Historically, when dispersion model estimates are used to assist in judging whether short-term NAAQS will be met, and ultimately in specifying

appropriate emission limits, one of three types of concentration estimates is used: (1) the highest of all estimated concentrations, (2) the second-highest of all estimated concentrations, or (3) the highest of second-highest concentrations estimated for a field of receptor sites. The highest of second-highest concentrations for a field of receptors is obtained as follows: (1) frequency distributions of short-term concentrations are estimated for each site in a field of receptors; (2) the highest estimated concentration at each receptor is discarded; (3) the highest of the remaining concentration estimates from the field of receptor sites is identified. Throughout this guideline that concentration estimate is referred to as the "highest, second-highest" concentration.

The first two types of estimates have been applied most often in specifying emission limits. However, they may be unnecessarily restrictive in many situations. The third type of estimate is more consistent with the criteria for determining violations of the NAAQS, which are identified in "Guidelines for Interpretation of Air Quality Standards."[3] That guideline specifies that a violation of a short-term standard occurs at a site when the standard is exceeded a second time. Thus, emission limits which are to be based on an averaging time of 24-hours or less should be based on the highest, second-highest estimated concentration plus a background concentration which can reasonably be assumed to occur with that concentration. (See the section on background air quality for a discussion of the factors and variety of situations that should be considered.)

An estimate of the highest, second-highest concentration which is based on many well-chosen receptor sites may well reveal previously unidentified "hot spots." Such an estimate may provide a more conservative and realistic indication of the potential for NAAQS violations and of the appropriate emission limits than do actual measurements at a few monitoring sites. However, if the data available for modeling are limited to a short period, or source data are generalized, the estimated highest, second-highest concentration is unlikely to provide a true indication of the threat to air quality standards. Thus it is essential that an adequate data base be available (see Section 5.0). Data for a time period of sufficient length should be considered so that there is reasonable certainty that meteorological conditions associated with the greatest impacts on air quality are identified. Similarly, detailed source data are required so that the air quality impact can be assessed for the source conditions likely to result in the greatest impact.

There are two exceptions to the above requirement to use the highest, second-highest estimated concentrations. The first situation occurs where monitored air quality data from specific sites indicate that concentrations greater than those estimated can occur with little or no impact from the source(s) in question. For the purpose of specifying emission limits, these measured concentrations should be ranked ahead of the estimated concentrations in the frequency distribution of concentrations at that specific monitoring (receptor) site.

The second situation occurs where the Regional Administrator identifies inadequacies in the data base or the models for a particular

application. As a result of these inadequacies he may determine that there is a lack of confidence in an emission limit based on the highest, second-highest concentration or that this concentration simply cannot be estimated. In this case, until such time as the necessary data bases are acquired or analytical techniques are improved, the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified.

3.2 New Source Reviews

Reviews for new sources that require an air quality impact analysis should determine if the source will (1) cause or exacerbate violations of a NAAQS or (2) cause air quality deterioration which is greater than allowable increments. For reviews relative to both the NAAQS and prevention of significant deterioration (PSD), the air quality impact analysis should generally be limited to the area where the impact exceeds "significant concentration increments." Such significant increments are defined in EPA's PSD regulations (40 CFR 52.21) and in EPA's Emission Offset Ruling (40 CFR Part 51, Appendix S). In addition, due to the uncertainties of estimates for large downwind distances, the air quality impact analysis should generally be limited to a downwind distance of 50 kilometers from the source, regardless of the above mentioned significant increments. The following subsections further identify requirements for concentration estimates associated with air quality standards and with prevention of significant deterioration.

3.2.1 Meeting Air Quality Standards

For each new source or major modification of a source which would increase allowable emissions by 50 tons per year, 500 pounds per day, or

100 pounds per hour, an air quality analysis should be performed to determine if the source will cause or exacerbate a violation of a NAAQS. For such new sources located in an attainment area, the concentration estimates should meet the same requirements that are applicable to control strategy evaluations. The determination of whether or not the source will cause an air quality violation should be based on (1) the highest estimated concentration for annual averages and (2) the highest, second-highest estimated concentration for averaging times of 24-hours or less. The most restrictive standard should be used in all cases to establish the potential for an air quality violation. Background concentrations should be added in assessing the source's impact. The two exceptions to the shorter-term averaging times which were noted in the preceding section also apply here; i.e., monitored data with higher concentrations and inadequacies in data bases or model.

3.2.2 Prevention of Significant Deterioration

Air quality models should be used in all significant deterioration evaluations. Allowable increments for sulfur dioxide and particulate matter are set forth in the Clean Air Act Amendments of 1977.[2] These maximum allowable increases in pollutant concentrations may be exceeded once per year, except for the annual increment. Thus, in significant deterioration evaluations for short-term periods the highest, second-highest increase in estimated concentrations should be less than or equal to the permitted increment.

Since the Clean Air Act Amendments express special concern for Class I PSD areas, any expected impacts for these areas must be considered. Thus, the distance limitation of 50 kilometers and the significant

concentration increments discussed in the introduction to Section 3.2 do not apply. In addition, where an exemption to the Class I increments is requested and approved pursuant to section 165(d)(2)(D) of the Clean Air Act, the source may cause the Class I increments to be exceeded on a total of 18 days during any annual period. In this case, it is necessary to select the highest estimated concentration in the field of receptors for each of the 365 days. These 365 values are then ranked and the 19th highest is used to determine emission limits. However, the highest, second-highest concentration may not exceed a somewhat higher increment specified in section 165(d)(2)(D)(iii).

4.0 AIR QUALITY MODELS

This Section recommends air quality models* for a wide variety of specific applications. It identifies factors that determine the suitability of models for individual situations, presents classes and subclasses of models and addresses special modeling problems.

Air quality models recommended in this section are state-of-the-art analytical techniques that make it possible to perform control strategy evaluations and new source/reviews, including prevention of significant deterioration. However, the responsible Regional Administrator may find that (1) the recommended air quality model is not appropriate for the particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other models deemed appropriate by the Regional Administrator may be used. However, all deviations from this guide should be fully supported and documented.

It must not be construed that the models recommended in this guide are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality. Similar models that are available from other governmental agencies and private consultants have been summarized and discussed by Lamb, et al.,[6] Moses,[7] Stern[8] and others.

*A discussion of each specific model or refined analytical technique is presented in Appendix A. Some of the models recommended here are also applicable to the development and use of Supplementary Control Systems (SCS). However, such control systems are not considered in the context of this guideline and the reader is referred to other publications on SCS.[4,5]

In all cases, and particularly when models and data bases other than those recommended in this guide are proposed, early discussions among the Regional Office staff, appropriate federal land managers, the control agencies and industry representatives can be invaluable and are encouraged. Concurrence on the data base, modeling techniques and overall technical approach, prior to the actual analyses, will help avoid disagreements concerning the final results and may reduce the later need for additional analyses. The Office of Air Quality Planning and Standards is routinely available to the Regional Offices for consultation on particularly difficult or complex problems.

It should be noted that models applicable to photochemical oxidants are not discussed in this guide. These models are undergoing a critical review. Requirements for such models and associated data bases will be specified at a later time.

4.1 Suitability of Models

The extent to which a specific air quality model is suitable for the evaluation of source impact and control strategies depends upon several factors that should be judged by the responsible Regional Administrator. These include (1) the detail and accuracy of the data base, i.e., emission inventory, meteorological data, air quality data; (2) the meteorological and topographic complexities of the area; (3) the technical competence of those undertaking such simulation modeling; and (4) the resources available. These factors, as well as others deemed appropriate by the responsible Regional Administrator, should be considered in determining the suitability of a particular model application.

The data base required for air quality models includes source data, meteorological data and air quality data (see Section 5.0). Appropriate data should be available before any attempt is made to apply a model. A model which requires detailed, precise input data should not be applied when such data are unavailable. However, assuming the data are adequate, the greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distinguish the effects of various control strategies.

Most air quality models that describe atmospheric transport and dispersion apply to areas with relatively simple topography. However, areas subject to major topographic or marine influence experience meteorological complexities that are extremely difficult to simulate. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time that better models and data bases become available.

Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. Whenever a model is applied, the services of knowledgeable, well-trained air pollution engineers, meteorologists and air quality analysts should be engaged. The need for specialists is particularly critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly or with inappropriately chosen data can lead to serious misjudgments regarding the source impact or the effectiveness of a control strategy.

The resource demands generated by use of air quality models vary widely depending on the specific application. Resources required are dependent on the nature of the model and its complexity, the detail of the data base, the difficulty of the application, and the amount and level of expertise required. The costs of manpower and computational facilities are also important factors.

4.2 Classes of Models

The air quality modeling procedures discussed in this guide can be categorized into four generic classes: Gaussian, numerical, statistical or empirical, and physical. Within some of these classes a large number of individual "computational algorithms" exist, each with its own specific applications. While each of these algorithms may have the same generic basis, e.g., Gaussian, it is accepted practice to refer to them individually as models. For example, the Climatological Dispersion Model, the Air Quality Display Model and the Texas Climatological Model are commonly referred to as individual models. In fact, they are all variations of a basic Gaussian model. In many cases the only real difference between models is the degree of detail considered in the input or output data.

Gaussian models are generally considered to be state-of-the-art techniques for estimating the impact of nonreactive pollutants. Numerical models are more appropriate than Gaussian models for multi-source applications which involve reactive pollutants. However, they frequently require more extensive resources and are not as widely applied. Statistical or empirical techniques are frequently employed in situations where incomplete scientific understanding of the physical and chemical

processes make the use of a Gaussian or numerical model impractical. Various specific models of these three generic types are recommended in this guideline.

Physical modeling, the fourth generic type, involves the use of wind tunnel or other fluid modeling facilities. This type of modeling may be very useful in evaluating the air quality impact of a source or group of sources in a geographic area limited to a few square kilometers. Where physical modeling is available and applicable, it is recommended. However, physical modeling is a complex process which requires a high level of technical expertise and is beyond the scope of this guide.

In addition to the various classes of models, this guide considers two levels of sophistication. The first level consists of general, relatively simple estimation techniques that provide conservative estimates of the air quality impact of a specific source, or source category. The purpose of such techniques is to eliminate from further consideration those sources that clearly will not cause or contribute to ambient concentrations in excess of NAAQS or allowable concentration increments. Conversely, these techniques can be used to identify those control strategies that have the potential to meet NAAQS and allowable increments. The second level consists of those analytical techniques which provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies.

In some cases, the first level of models may be equated with screening techniques to determine if a second or more refined analysis is required. However, while the use of screening techniques followed by a more refined analysis is desirable, there are situations where the screening techniques are practically and technically the only viable option for estimating source impact and evaluating control strategies. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3 Recommended Models

To meet the need for consistency identified in Section 2, selected point source and multi-source models applicable to specific pollutants and averaging times are recommended in this subsection. Ideally, air quality models that are recommended should meet prescribed standards of performance for particular applications and should be subjected to specific validation procedures. However, there are no generally accepted standards of performance and validation procedures (see pp. 41-43). The models recommended in this guideline are simply those which are (1) representative of the state-of-the-art for atmospheric simulation models and (2) most readily available to air pollution control agencies.

Nevertheless, the need for information on the accuracy of these models exists. Limited information on the accuracy of recommended models is presented in Appendix A. More detailed information is referred to in some of the individual user's guides. However, additional studies which encompass a wider range of sources and climatic regimes are needed since there is a general lack of reported information on the accuracy of the models. This is true of all classes of models, including widely

applied Gaussian models. Whenever possible, the user is encouraged to further validate models recommended in this guide, or other models that may be used.

4.3.1 Point Source Models for Sulfur Dioxide and Particulate Matter (All Averaging Times)

Gaussian models are considered to be state-of-the-art techniques for estimating concentrations of sulfur dioxide and particulate matter. They are the best choice for most point source evaluations. For all point sources two levels of sophistication in the use of models are suggested. The first level is composed of models which can provide a preliminary estimate of concentrations. If it is estimated by the screening technique that a source may cause a concentration that is an unacceptable portion of an allowable air quality increment, then that source should be subjected to a more refined analysis.

For flat terrain situations that have no significant meteorological complexities, there are several standard publications[9-11] and computerized models[12] that can be used for screening. In addition Pooler[13] and Carpenter et al.[14] have discussed simplified techniques for estimating concentrations during inversion-breakup fumigation. Lyons[15] has summarized information and techniques applicable to lake/sea breezes. Huber and Snyder[16,17] and Briggs[18] have presented various techniques applicable to aerodynamic downwash. Several authors[19-22] have outlined techniques that are useful for situations where long-range transport (greater than 50 kilometers) is important. The Valley Model[12,23] is applicable to some complex terrain situations; Egan[24] has summarized information on other applicable techniques. Volume 10 of the Guidelines for Air Quality

Maintenance Planning and Analysis,[25] "Procedures for Evaluating Air Quality Impact of New Stationary Sources" has summarized, in a format useful for screening, techniques applicable to both flat terrain and more complex situations; those techniques are recommended for use.

In those cases where a more refined analysis is required and there are no significant meteorological or terrain complexities, the Single Source (CRSTER) Model[12,26] is recommended for use. In some cases specialized data outputs from models comparable to the Single Source (CRSTER) Model may be needed. Where these models* estimate essentially the same concentration as the Single Source (CRSTER) Model, their modified computer codes which provide more useable outputs are acceptable.

If meteorological or terrain complexities cause substantial uncertainties, then a model that is more detailed or more suitable than the Single Source (CRSTER) Model should be applied. No refined, widely available models applicable to complex situations are identified. It is recommended that each complex situation be treated on a case-by-case basis with the assistance of expert advice.

If the data bases required to apply the Single Source (CRSTER) Model are unavailable, or if other refined models applicable to a complex situation do not exist, then it may be necessary to base estimates of source impact and the evaluation of control strategies on only the estimates provided by the screening techniques. In such cases, an

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*One example of such a model is MULTIMAX. See Moser, J. H. "MULTIMAX: An Air Dispersion Modeling Program for Multiple Sources, Receptors, and Concentration Averages." Shell Development Company, Houston, Texas 77001, December, 1977.

attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

Models specified here and in the following subsection are also applicable to stationary sources of lead pollutants, provided the pollutants can be assumed to behave as a gas.

4.3.2 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Annual Average)

Due to the complexity of most multi-source situations and the wide acceptability of several models, a screening process is not generally conducted. If a preliminary assessment of the adequacy of a control strategy is desired, the Rollback Model[27] may be used. However, in most cases such a screening does not constitute an adequate control strategy demonstration.

The Climatological Dispersion Model (CDM/CDMQC),[12,28,29] the Air Quality Display Model (AQDM)[30] and the Texas Climatological Model (TCM)[31] are recommended for evaluating the long-term impact of urban multi-source complexes. In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.3 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Short-Term Averages)

As noted in the preceding subsection, a Rollback Model may be used for the preliminary assessment of a control strategy. The Gaussian-Plume

Multiple-Source Air Quality Algorithm (RAM)[12,32] is recommended for evaluating the impact of multi-source complexes on air quality averaged over short-term periods. Versions of this model are applicable to both urban and rural situations. The Texas Episodic Model (TEM)[33] may be used if the data bases required to apply RAM are unavailable. Also, if the resources required to operate RAM or TEM are not available, then CDMQC or AQDM may be used to estimate short-term concentrations of SO_2 and particulate matter. CDMQC and AQDM incorporate procedures, such as that discussed by Larsen,[34] to estimate 3-hour and 24-hour average concentrations from annual average concentration estimates. Such statistical techniques are valid only in urban, multi-source areas and should not be used in situations dominated by large point sources.

In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.4 Models for Carbon Monoxide

The recommendations for point source screening procedures and models are also applicable to evaluate point sources of carbon monoxide (CO). The models, procedures and requirements described in Volume 9 of the Guidelines for Air Quality Maintenance Planning and Analysis,[35] "Guidelines for Review of the Impact of Indirect Sources on Ambient Air Quality," are recommended for screening all sources of CO which fulfill

the definition of an indirect source. The indirect source guideline is based on the use of HIWAY[12,36] and other simple dispersion techniques. It is acceptable to apply these techniques independent of the indirect source guideline, if it is found that the guideline does not adequately consider a wide enough set of circumstances. If a preliminary assessment of the adequacy of a control strategy applicable to an urban area is desired, the Rollback Model may be used.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for this model are available, it may be used. Examples of such refined techniques are APRAC-1A[12,37] and its revision, APRAC 2.[38] However, if a region-wide analysis is necessary and the complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.5 Models for Nitrogen Dioxide (Annual Average)

The recommendations for point source screening techniques and models are also applicable to evaluate point sources of nitrogen oxides (NO_x) under limited circumstances. The circumstances require an assumption that all NO_x is emitted in the form of NO_2 or is converted to NO_2 by the time it reaches the ground and that NO_2 is a nonreactive pollutant.

For sources located where atmospheric photochemical reactions are significant, a Rollback Model may be used as a preliminary assessment to

evaluate the control strategies for multiple sources (mobile and stationary) of NO_x. Another acceptable screening technique for multiple sources is to make an assumption similar to that required for point sources and then to use a model for nonreactive pollutants, such as CDM.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for this model are available, it may be used to estimate average concentrations of NO_2. However, if a region-wide analysis is necessary and the complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.4 Special Situations

Models with a wide applicability are not generally available for dealing with long-range transport, deposition, wind-blown particulate matter, unique topographic or meteorological circumstances, and nontypical sources such as open burning.[39] Thus, with proper support and documentation, the Regional Administrator may determine that a particular model, not specifically recommended here, is appropriate for a special situation. Examples of these situations are discussed for clarification.

The administration of the national prevention of significant deterioration policy may require that the air quality impact of a source be estimated for great distances downwind. It is uncertain, however, what the impact of sources at such great distances is. Knowledge of the

dispersion coefficients for air quality models* becomes increasingly tenuous with downwind distance. Plume transport beyond about 50 kilometers usually requires substantial travel time. As travel time increases, diurnal variations in meteorological conditions and movement of weather systems are more likely to alter plume trajectories and dispersion characteristics. Even though the impact at greater than 50-100 kilometers may be relatively small, the impact can still be significant for large sources and for situations where the merging of plumes occurs. Techniques are available to examine these impacts, but only limited experience in their use is currently available. If it appears that a large source (for example, a 2000-MW coal-fired power plant meeting new source performance standards) may constitute a threat to ambient air quality standards or prevention of significant deterioration increments at large distances, that source should be considered on a case-by-case basis with available techniques.[19-22,25]

The models presented in this guide for estimating ambient concentrations of suspended particulate matter assume that the particles disperse as a gas and emanate from well-defined sources. Unfortunately, in many areas, particularly where the air quality standards are not being attained, these assumptions may not hold. Windblown dust, re-entrained street dust, dry-land farming, and raw-material handling

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*Vertical dispersion in these situations is more appropriately treated with numerical models. There are also inherent difficulties with Gaussian models in cases where plume depletion through chemical and physical removal processes is significant. Plume depletion would normally be significant at distances beyond about 50 kilometers for tall stacks under conditions of appreciable vertical mixing, and at considerably shorter distances for near-ground sources.

operations, all of which are often referred to as fugitive dust sources, can be significant sources of particulate matter.[40] EPA has several on-going studies concerned with fugitive sources of dust; however, the rate and distribution of particulate emissions from these sources is not yet fully known. As a result, a widely applicable model for routinely estimating particulate concentrations attributable to fugitive sources is not available.[41]

Terrain dominated flows and wakes that develop in the vicinity of pollutant sources are involved in many situations.[16-18,23,24] The basic theoretical principles of these flows are generally understood. However, the variety of terrain features is so great and the spectrum of atmospheric circumstances so broad that no generally applicable model is available that can adequately deal with the range of conditions encountered.

EPA will provide guidance on data bases and assessment procedures to deal with special situations as the results of on-going field investigations and research on these matters become available.

5.0 DATA REQUIREMENTS

It is essential that appropriate source and meteorological data be used with any recommended model. Such data, and related procedures for estimating these data, constitute an integral part of the model. It is often overlooked that few of the variables input to a model are directly measured or routinely available. Submodels must appropriately convert the available source and meteorological data to a form that the air quality model can accept. It is also important that a variety of load/emissions conditions, and that a wide range of meteorological conditions based on several years of data, be considered in evaluating control strategies and in determining source impact for new source reviews, including prevention of significant deterioration. In addition, there is a need to judiciously choose receptor sites and to specify background air quality. This section identifies requirements for these data bases.

5.1 Source Data

Sources of pollutants generally can be classified as point, line and area sources. Point sources are generally considered to be those that emit a substantial amount of an air pollutant, e.g., 50 tons per year, from a stack or group of stacks. Line sources are generally confined to roadways and streets along which there are well-defined movements of motor vehicles. Area sources include the multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square. Descriptions of individual models should be referenced for specific emissions inventory requirements.

For situations involving one or a few point sources the following are minimum requirements for new source review and control strategy evaluations. Design process rate or design load conditions must be considered in determining pollutant emissions. Other operating conditions that may result in high pollutant concentrations should also be identified.* A range of operating conditions, emission rates, and physical plant characteristics based on the most recently available data, should be used in the model with the multiple years of meteorological data (see Section 5.2) to estimate the source impact. The following example (power plant) typifies the kind of data on source characteristics and operating conditions that are required:

1. Plant layout. The connection scheme between boilers and stacks, and the distance and direction between stacks, building parameters (length, width, height, location and orientation relative to stacks) for plant structures which house boilers, control equipment, etc.

2. Stack parameters. For all stacks, the stack height and diameter (meters), and the temperature (K) and volume flow rate (actual cubic meters per second) or exit gas velocity (meters per second) for operation at 100 percent, 75 percent and 50 percent load.

3. Boiler size. For all boilers, the associated megawatts and pounds of steam per hour, and the design and/or actual fuel consumption rate for 100 percent load for coal (tons/hour), oil (barrels/ hour), and natural gas (thousand cubic feet/hour).

4. Boiler parameters. For all boilers, the percent excess air used, the boiler type (e.g., wet bottom, cyclone, etc.), and the type of firing (e.g., pulverized coal, front firing, etc.).

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*Malfunctions which may result in excess emissions are not considered to be a normal operating condition. They generally should not be considered in determining allowable emissions. However, if the excess emissions are the result of poor maintenance, careless operation, or other preventable condition, it may be necessary to consider them in determining source impact.

5. Operating conditions. For all boilers, the type, amount and pollutant contents of fuel, the total hours of boiler operation and the boiler capacity factor during the year, and the percent load for winter and summer peaks.

6. Pollution control equipment parameters. For each boiler served and each pollutant affected, the type of emission control equipment, the year of its installation, its design efficiency and mass emission rate, the date of the last test and the tested efficiency, the number of hours of operation during the latest year, and the best engineering estimate of its projected efficiency if used in conjunction with coal combustion; data for any anticipated modifications or additions.

7. Data for new boilers or stacks. For all new boilers and stacks under construction and for all planned modifications to existing boilers or stacks, the scheduled date of completion, and the data or best estimates available for items 1 through 6 above following completion of construction or modification.

Typically for line sources, such as streets and highways, data are required on the width of the roadway and its center strip, the types and amounts (grams per second per meter) of pollutant emissions, the number of lanes, the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments must be specified in appropriate grid coordinates. More detailed information and data requirements for modeling mobile sources of pollution are provided in the guideline[35] on indirect sources.

For multi-source urban situations, detailed source data are often impractical to obtain. In these cases, source data should be based on annual average conditions. Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated, representative stack height for the area, the location of the centroid or the southwest corner of the source in appropriate grid coordinates. If the model accepts data on area-wide diurnal variations in emissions, such as those estimated by emissions models which

are based on urban activity levels and other factors, those data should be used.

In cases where the required source data are not available and cannot be obtained, the data limitation should be identified. Due to the uncertainties associated with such a limitation the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

For control strategy evaluations the impact of growth on emissions should be considered for the next 10-20 year period. Increases in emissions due to planned expansion of the sources considered or planned fuel switches should be identified. Increases in emissions at each source which may be due to planned expansion of the sources considered or planned fuel switches should be identified. Increases in emissions at each source which may be associated with general industrial/commercial/residential expansion in multi-source urban areas should also be considered. However, for new source reviews, the impact of growth on emissions should generally be considered for the period prior to the start-up date for the source.* Such changes in emissions should consider increased area source emissions, changes in existing point source emissions which were not subject to preconstruction review, and emissions due to sources with permits to construct, but have not yet started operation.

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*A new source may result in specific and well defined secondary emissions which can be accurately quantified. Secondary emissions are those resulting from operation of the source, but not directly emitted by the source, e.g., emissions from shipping at a port terminal. The reviewing authority should consider such secondary emissions in determining whether the source would cause or contribute to a violation of the NAAQS. However, since EPA's authority to perform indirect source review relating to parking-type facilities has been restricted by statute, consideration of parking-type secondary impacts is not required.

5.2 Meteorological Data

For a dispersion model to provide useful and valid results, the meteorological data used in the model must be representative of the transport and dispersion conditions in the vicinity of the source that the model is attempting to simulate. The representativeness of the data is dependent on (1) the proximity of the meteorological monitoring site to the area under consideration, (2) the complexity of the terrain in the area, (3) the exposure of the meteorological monitoring site and (4) the period of time during which the data are collected. The representativeness of the data can be adversely affected by large distances between the source and receptors of interest and valley-mountain, land-water, and urban-rural characteristics of the area.

For new source review and control strategy evaluation, the meteorological data required as a minimum to describe transport and dispersion in the atmosphere are wind direction, wind speed, atmospheric stability, mixing height or related indicators of atmospheric turbulence and mixing. Site-specific data are preferable to data collected off-site. The availability of such meso- and micro-meteorological data collections permits more detailed meteorological analyses and subsequent improvement of model estimates. Local universities, industry, pollution control agencies and consultants may be sources of such data. The parameters typically required can also be derived from routine measurements by National Weather Service stations. The data are available as individual observations and in summarized form from the National Climatic Center, Asheville, N. C. Descriptions of individual models should be referred to for specific meteorological

data requirements. Many models require either hourly meteorological data or annual stability wind roses.

It is preferable for the meteorological data base used with the air quality models to include several years of data. Such a multi-year data base allows the consideration of variations in meteorological conditions that occur from year to year. The exact number of years needed to account for such variations in meteorological conditions is uncertain and depends on the climatic extremes in a given area. Generally five years[42] yields an adequate meteorological data base. However, if long-term data records are not available, it may be necessary to limit the modeling and subsequent analyses to a single year of meteorological data. The use of one year of data might also be justified if the climatological representativeness of that data can be demonstrated. A longer record from a nearby National Weather Service site could be used to check for representativeness.

The number of National Weather Service stations for which multiple years of hourly weather data are available is increasing significantly. Several EPA offices have ordered such data for a large number of stations. It is clear that more detailed analyses than previously considered for SIP evaluations and new source review are necessary. Thus, for areas where meteorological conditions are adequately represented by weather stations, the use of multiple years of meteorological data appears to be viable and justified.

Where representative meteorological observations are not available, the concentration estimates may be limited to consideration of worst case conditions. An analysis of worst case conditions should be based on

reasonable interpretations of climatological data and should consider such critical plume characteristics as looping, coning, limited mixing, fumigation, aerodynamic downwash and plume impaction on terrain. Due to the uncertainties of this approach, the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

5.3 Receptor Sites

A receptor site is a location for which an air pollution concentration is estimated. The choice of locations for receptor sites significantly affects the evaluation of source impact and control strategy effectiveness. It is most important to identify the location where the maximum concentrations occur, both short- and long-term. The receptors selected must allow sufficient spatial detail and resolution so that the location of the maximum or highest, second-highest concentration is identified.

The receptor sites in the vicinity of large point sources at which maximum concentrations are likely to occur can be identified by (1) estimating concentrations for a sufficiently dense array of receptors to identify concentration gradients and (2) subsequently refining the location of the maximum by estimating concentrations for a finer array of receptors in the general areas of maximum concentrations. Another technique is to use a simple model such as PTMAX[12] in combination with joint frequency distributions of wind speed, wind direction and stability to identify the downwind distance and direction at which the highest concentrations are most likely to occur. However, other areas around the source(s) should

not be ignored, particularly if they are on elevated terrain. In addition a receptor should be specified at any site where a monitor is located.

5.4 Background Air Quality

To adequately assess the significance of the air quality impact of a source, background concentrations must be considered. Background air quality relevant to a given source includes those pollutant concentrations due to natural sources and distant, unidentified man-made sources. For example, it is commonly assumed that the annual mean background concentration of particulate matter is 30-40 $\mu g/m^3$ over much of the Eastern United States.[43] Typically, air quality data are used to establish background concentrations in the vicinity of the source under consideration. However, where the source is not isolated, it may be necessary to use a multi-source model to establish the impact of all other nearby sources during dispersion conditions conducive to high concentrations.

If the point source is truly isolated and not affected by other readily identified man-made sources, two options for determining background concentrations from air quality data are available. The preferable option is to use air quality data collected in the vicinity of the source to determine mean background concentrations for the averaging times of interest when the point source itself is not impacting on the monitor. The second option applies when no monitors are located in the vicinity of the source. In that case, average measured concentrations from a "regional" site can be used to establish a background concentration.

For the first option it is a relatively straightforward effort to identify an annual average background from available air quality data. For

shorter averaging times, background concentrations are determined by the following procedure. First, meteorological conditions are identified for the day and similar days when the highest, second-highest estimated concentration due to the source occurs. Then the average background concentration on days with similar meteorological conditions is determined from air quality measurements. The background for each hour is assumed to be an average of hourly concentrations measured at sites outside of a 90° sector downwind of the source. The 1-hour concentrations are then averaged to obtain the background concentration for the averaging time of concern.

If air quality data from a local monitoring network are not available, then monitored data from a "regional" site may be used for the second option. Such a site should characterize air quality across a broad area, including that in which the source is located. The technique of characterizing meteorological conditions and determining associated background concentrations can then be employed.

If a small number of other identifiable sources are located nearby, the impact of these sources should be specifically determined. The background concentration due to natural or distant sources can be determined using procedures already described. The impact of the nearby sources must be summed for locations where interactions between the effluents of the point source under consideration and those of nearby sources can occur. Significant locations include (1) the area of maximum impact of the point source, (2) the area of maximum impact of nearby sources, and (3) the area where all sources combine to cause maximum impact. It may be necessary to identify these locations through a trial and error analysis.

If the point source is located in or near an urban multi-source area, there are several possibilities for estimating the impact of all other sources. If a comprehensive air monitoring network is available, it may be possible to rely entirely on the measured data. It is necessary that the network include monitors judiciously located so as to measure air quality at the locations of the point source's maximum impact and locations of the highest concentrations in the area. If the point source is not yet operating, its calculated impact can be added to these measured concentrations. If the source already exists and is contributing to the measured concentrations, its calculated contribution should be subtracted from the measured values to estimate the concentration caused by other man-made sources and by background.

If the monitored data are inadequate for such an analysis, then multi-source models can be used to establish the impact of all other sources. These models should be used for appropriate pollutants and averaging times to identify concentrations at the times and locations of maximum point source impact. The times and locations of maximum impact due to all other sources must also be identified. If a model is not available for the appropriate averaging times, statistical techniques can be used with an appropriate model to extrapolate from one averaging time to another. All statements in this guide regarding the data requirements and validity of air quality models are applicable to analyses of this type.

For control strategy evaluations, the impact of growth on area-wide emissions and on concentrations caused by nearby sources should also be considered for the next 10-20 year period. To determine concentrations

in future years, existing air quality should be proportionately adjusted by the anticipated percent change in emissions in the vicinity of individual monitoring sites. However, for new source reviews, changes in existing air quality should generally be considered for the period prior to the start-up date of the source (see Section 5.1).

6.0 MODEL VALIDATION/CALIBRATION

Any application of an air quality model may have deficiencies which cause estimated concentrations to be in error. When practical to obtain a measure of confidence in the estimates, they should be compared with observed air quality data and their validity determined.

The model validation process* consists of a series of analytical steps: (1) Comparing estimated concentrations with measured air quality data, (2) determining the cause of discrepancies, (3) correcting and improving data bases, (4) modifying the model (if necessary) in a manner that provides a better mathematical representation of physical reality, and (5) documenting, for others, the accuracy of the estimates. Statistical methods available for validation of models include skill scores, contingency tables, correlation analyses, time series and spatial analyses, and others. If evaluation by one or more statistical techniques indicates that the concentration estimates are not a satisfactory representation of observed concentrations, then it is likely that one or both of the following problems exist: the source, meteorological or air quality data are not appropriate, reliable and complete; or the model itself is inadequate for the area under consideration.

The availability and accuracy of the input data significantly influence the accuracy of the model estimates. The source factors that have the greatest impact on the accuracy of the estimates are the

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*There is a clear need for specific and uniform validation procedures and for standards of performance. The feasibility of specifying such procedures and standards for air quality models is being studied by EPA. However, for the present time, the generalized recommendations presented in this section are suggested for use.

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accuracy and completeness of the (1) emissions data, (2) physical plant parameters, and (3) site coordinates of the sources. Often the validation will reveal deficiencies in the emissions inventory, which can be corrected to improve the accuracy of the model estimates. The accuracy of the concentration estimates is also affected by the location and exposure of the instrumentation used for obtaining the meteorological data and the overall representativeness and completeness of those data. Similarly, the validation of the dispersion model is affected by the location, exposure and representativeness of the air quality sampling sites and by the accuracy and completeness of the air quality data itself. These data should be available for the same averaging times as the concentration estimates and should describe the spatial variation of pollutant concentrations across the area. If the air quality data are in any way unsuitable or incorrect, the accuracy of the dispersion model estimates cannot be determined.

The following factors most frequently cause a model to be considered inadequate or inappropriate for a given area: (1) The model is applied to an area with complex or unique terrain or meteorological conditions; (2) the source emissions vary markedly or irregularly with time; (3) the pollutant is subject to major or highly variable atmospheric chemical reactions or removal processes; (4) the model is applied to pollutants with characteristics other than those considered in its development. If any of these circumstances are encountered, it may be necessary to select a more appropriate model or appropriately modify the model being used.

When any analytical technique is employed, the analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the procedure. Thus, in all applications of models an effort should be made to identify the reliability of the model estimates for that particular area or similar areas and to determine the magnitude and sources of error associated with the use of the model. In addition, sensitivity analyses are useful for determining the effect of variations or uncertainties in the data bases on the range of likely concentrations. Such information may be very useful in determining source impact and evaluating control strategies. Where possible, information on sensitivity should be made available by the modeler.

Due to limitations of the data base, lack of scientific knowledge or limitations on time and resources, it may not always be possible to perform a thorough and complete model validation. Thus, in some situations, it has been necessary to revert to calibration of the model. Calibration of a model is the process of identifying systematic errors and applying a correction factor. In many cases this involves the application of regression analysis or other statistical techniques to adjust model estimates in order to increase agreement with measured data.

Calibration of long-term multi-source models is a widely used procedure. It is acceptable provided that reasonable resources have been expended to validate the model, e.g., the five steps listed at the beginning of this section. Limitations imposed by statistical theory on the reliability of the calibration process for long-term estimates

have been identified.[44] In some cases, though, calibration may be the only alternative for improving the accuracy of estimated concentrations and the control strategy evaluation. However, if the model accounts for less than 50 percent of the variation of measured concentrations, it is doubtful that there is justification for using the model.

Calibration of short-term models has not been widely performed and is subject to a greater amount of error and misunderstanding. There have been attempts by some to compare short-term estimates and measurements on an event-by-event basis and then to calibrate the model with results of the comparison. This approach is severely limited by uncertainties in source and meteorological data and thus one's ability to precisely estimate the concentration at an exact location for a specific increment of time. These uncertainties make attempts to calibrate a short-term model questionable. As a result, it appears that the most reliable direct comparison between estimated and measured short-term concentrations involves the upper percentiles of the respective frequency distributions. Even here, considerable variation may be found from site-to-site and plant-to-plant. In such comparisons[45,46] for one basic Gaussian point source model it was found that short-term estimates of highest concentrations are generally accurate within a factor of two. This accuracy is consistent with the empirical basis[47,48] for these models. However, in general, estimates which are both too high and too low may be expected.

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*UNAMAP has now been expanded to include 11 commonly used air quality models. The 11 computer codes include PTMAX, PTDIS, PTMTP, HIWAY, PAL, APRAC-1A, CDM, CDMQC, CRSTER, VALLEY and RAM.

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Glossary of Selected Terms

Air Quality - Ambient pollutant concentrations and their temporal and spatial distributions.

Algorithm - A specific mathematical calculation procedure.

Background - Ambient pollutant concentrations due to natural sources and distant, unidentified man-made sources.

Calibration - An adjustment applied to concentration estimates, based on a comparison with measured air quality data, in order to improve the accuracy of the model.

Computer code - A set of statements that comprise a computer program.

Model - A quantitative or mathematical representation or simulation which attempts to describe the characteristics or relationships of physical events.

Receptor - A location at which ambient air quality is measured or estimated.

Rollback - A simple model that assumes that if emissions from each source affecting a given receptor are decreased by the same percentage, ambient air quality concentrations decrease proportionately.

Screening Procedure - A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality.

Validation - Determination of the reliability of a model by comparing the model estimates with measured air quality data.

Appendix A

Summaries* of Recommended

Air Quality Models

*Summaries presented in this appendix are largely based on similar information summarized by J. J. Roberts (Ed.) in "Report to the U.S. EPA of the Specialists' Conference on the EPA Modeling Guidelines," Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1977.

A.1 AIR QUALITY DISPLAY MODEL (AQDM)

Reference: TRW Systems Group. "Air Quality Display Model." Prepared for National Air Pollution Control Administration, DHEW, U.S. Public Health Service, Washington, D.C., November 1969, (NTIS PB 189194).

Abstract: AQDM is a climatological steady state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level in urban areas. A statistical model based on Larsen[1] is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

For both point and area sources:

$$x = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k\ell m} \, \chi_{k\ell m}$$

where:

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\,\sigma_z\,u_\ell} \left(\frac{c-y}{c}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{u_\ell L} \left(\frac{c-y}{c}\right) \quad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$

x_L defined by $\sigma_z(x_L) = 0.47L$

y = crosswind distance between receptor and sector k centerline

c = sector width at receptor location

$\sigma_z(x) = ax^b + c$; a,b,c = functions of stability class
a,b,c for neutral conditions split into
x > 1000m case and x ≤ 1000m case.

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Q = emission rate (g/s)

H = plume height (m)

u = wind speed (m/s)

ϕ = relative frequency of occurrence from stability wind rose

σ_z = vertical standard deviation of plume concentrations (m)

x = downwind distance (m)

a. Source-Receptor Relationship

Arbitrary location and stack height for each point source
Arbitrary location and size for each area source
Up to 225 receptors located on uniform rectangular grid
Up to 12 user-specified receptor locations
Unique release height for each point, area source
Unique separation for each source-receptor pair
Receptors at ground level
No terrain differences between source and receptor

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
Each source treated by effective single point source approximation
No temporal variation allowed

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Use of the Briggs plume rise formulation is recommended
Calculations based on single arbitrary values of stack diameter, stack gas exit velocity and stack gas temperature for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash
If stack height plus plume rise is greater than mixing height, ground level concentration assumed equal to zero

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes

No variation in wind speed with height
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Climatological approach
Uniform 22.5° wide plume assumed
Frequency of occurrence interpolated between sector centerlines
Averaging times from 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[2]
Neutral stability split internally into 60% day, 40% night
Dispersion coefficients from Pasquill and Gifford
Neutral dispersion coefficients used for stable class
No provision for variations in surface roughness

i. Chemistry/Reaction Mechanism

No provision for treatment

j. Physical Removal

No provision for treatment

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): perfect reflection
Upper boundary (mixing height): no effect until $\sigma_z \geq 0.47L$ (this occurs at $x = x_L$) For $x_L < x < 2x_L$, σ_z is linearly interpolated between its value at x_L and its value at $2x_L$

m. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Emission rate - not correlated with any other factor
Non-sequential (climatological) limited correlation
Mixing height adjusted according to stability class:
  Class A - 1.5 times the afternoon climatological value
  Classes B, C, and D(day) - equal to the afternoon climatological value
  Class E - 100 meters

n. Validation/Calibration

Calibration option available
Validation is routinely done in most applications. Thus a large number of validations have been carried out, although few appear in the literature. This model, with the Briggs plume rise formulas, typically estimates concentrations ranging from nearly correct to a factor of two high

o. Output

1 month to 1 year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen procedure (typically 1 - 24 hours)
Assumes
(1) lognormal concentration distribution,
(2) power law dependence of median and maximum concentrations on averaging time
Up to 225 gridded receptor locations, 12 arbitrary locations
Individual point, area source culpability list for each receptor

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Useable for urban areas only
In general, CDM/CDMQC is preferred over AQDM

A.2 APRAC-1A

Reference: Mancuso, R. L. and F. L. Ludwig. "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program." Publication No. EPA-650/3-73-001 (NTIS PB 213091), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1972.

Abstract: APRAC is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, mainly from sources upwind of the city of interest; intraurban, from freeway, arterial, and feeder street sources; and local, from dispersion within a street canyon. APRAC requires an extensive traffic inventory for the city of interest.

Equations:

$$\text{Extraurban - } \chi_e = \frac{5.15 \times 10^{-11} F}{uL}$$

F = annual fuel consumption within 22.5° sector extending from 32 km to 1000 km upwind of receptor.

$$\text{Intraurban - } \chi_{ij} = \frac{0.8 Q_i}{u\, a_{ij}} \quad \frac{x_{i+1}^{1-b_{ij}} - x_i^{1-b_{ij}}}{1-b_{ij}}$$

Until this expression equals the "box model value"

$$\frac{Q_i}{uL}(x_{i+1} - x_i)$$

Thereafter the box model formula is used.
i = upwind area segment label
j = stability class label
a_{ij} and b_{ij} from $(\sigma_z)_{ij} = a_{ij} \chi^{b_{ij}}$ for x within segment i

$$\text{Street Canyon - Lee side} \quad \chi_L = \frac{KQ_s}{(u+0.5)[(x^2+z^2)^{1/2} + L_o]}$$

$$\text{Windward side} \quad \chi_w = \frac{KQ_s(H-z)}{(u+0.5)\,WH}$$

Intermediate wind direction(less than ± 30° from street (direction)

$$\chi_L = \frac{1}{2}(\chi_L + \chi_W)$$

where:

x = horizontal distance from traffic lane (m)

z = height above pavement (m)

K = constant ≈ 7

L_o = vehicle size ≈ 2m

u = rooftop wind speed (m/s)

Q_s = CO emission rate (g/s-m)

W = Street width (m)

H = average building height ≈ 38.8 m

a. Source-Receptor Relationship

User specifies set of traffic links (line sources) by providing link end points, road type, daily traffic volume
The traffic links may have arbitrary length and orientation
Off-link traffic allocated to two mile square grid
Link traffic emissions are aggregated into a receptor oriented area source array
The boundaries of the area sources actually treated are (1) arcs at radial distances from the receptor which increase in geometric progression, (2) the sides of a 22.5° sector oriented upwind for distances greater than 1000 m, and (3) the sides of a 45° sector oriented upwind for distances less than 1000 m.
A similar area source array is established for each receptor
Sources assumed at ground level
Up to 10 receptors
Receptors at ground level
Receptor locations are arbitrary
Four internally defined receptor locations on each user-designated street are used in a special street canyon sub-model

b. Emission Rate

Daily traffic volume for each link and off-link grid square is input and modified by various factors to produce hour-by-hour emissions from each link
Link emissions aggregated as described above: sector area source contributions obtained analytically
Off-link traffic emissions on the two mile square grid are added into sector area sources
In street canyon sub-model, a separate hourly emission rate is provided by user for the link in question

c. Chemical Composition

Treats one inert pollutant

d. Plume Behavior

Does not treat plume rise
Does not treat fumigation or downwash except in street canyon sub-model
In street canyon sub-model, a helical circulation pattern is assumed

e. Horizontal Wind Field

Hourly wind speed and direction in tens of degrees are input
No variation of wind speed or direction with height
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero except in street canyon sub-model
Helical circulation assumed by street canyon sub-model

g. Horizontal Dispersion

Sector averaging uniform distribution within sectors
22.5° sectors beyond 1 km
45.0° sectors within 1 km

h. Vertical Dispersion

Semi-empirical/Gaussian plume
6 stability classes; stability class determined internally from user-supplied meteorological data [modified from Turner[2]]
Dispersion coefficients from McElroy and Pooler[3], modified using information in Leighton and Ditmar[4]
No adjustments made for variations in surface roughness
Downwind distance variation of σ_z assumed to be ax^b for purposes of doing analytic integration
In street canyon sub-model, empirical function of wind speed and street width and direction is used

i. Chemistry/Reaction Mechanism

Single inert pollutant

j. Physical Removal

Not treated

k. Background

Box model used to estimate contribution from upwind sources beyond 32 km based on wind speed, mixing height, annual fuel consumption
In street canyon sub-model, contribution from other streets is included in background

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection; ignores effect until concentration equals that calculated using box model; uses box model (uniform vertical distribution) thereafter
Mixing height determined from morning radiosonde data as follows:
midnight to dawn: constant at pre-dawn value obtained using minimum urban temperature
dawn to sunset: afternoon maximum temperature used to obtain maximum height; hourly values obtained from surface temperature variations
sunset to midnight: linear interpolation with time

m. Emission and Meteorological Correlation

Emissions a function of hour of the day and day of the week
Meteorological parameters are functions of hour of the day

n. Validation/Calibration

No calibration option provided
One validation study documented by authors of the model

o. Output

Hourly concentration values at each receptor
Frequency distribution based on hourly values can be obtained

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Limited to urban areas
No means for including point sources

A.3 CLIMATOLOGICAL DISPERSION MODEL (CDM)

References: Busse, A. D. and J. R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.

Brubaker, K. L., P. Brown, and R. R. Cirillo. "Addendum to User's Guide for Climatological Dispersion Model." Publication No. EPA-450/3-77-015, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May 1977.

Abstract: CDM is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground-level receptor in an urban area. An expanded version (CDMQC) includes a statistical model based on Larsen[1] to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

$$\chi_{point} = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{\ell=1}^{6} \sum_{m=1}^{6} Q_n \, \theta_{kn\ell m} \, S_{\ell m} \, (\rho_n)/\rho_n$$

$$\chi_{area} = \frac{16}{2\pi} \int \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m} \, S_{\ell m}(\rho) \right] d\rho$$

$$\text{with } q_k(\rho) = \int_{\text{sector } k} Q(\rho,\theta) d\theta$$

$$S_{\ell m}(\rho) = \frac{2}{\sqrt{2\pi}\, \sigma_z \, u_\ell} \exp\left[-\frac{1}{2} \left(\frac{H}{\sigma_z}\right)^2 \right] \exp\left[-\frac{0.692\, \rho}{u_\ell \, T_{1/2}} \right]$$

$$\text{for } \sigma_z \leq 0.8L$$

$$S_{\ell m}(\rho) = \frac{1}{u_\ell L} \exp\left[-\frac{0.692\,\rho}{u_\ell T_{1/2}}\right] \quad \text{for } \sigma_z > 0.8L$$

$\sigma_z = a\rho^b$; a,b = functions of stability class (m) and downwind distance (ρ) - three ranges of distance used: 100-500 m, 500-5000 m, and 5000-50,000 m

k_n = wind sector appropriate to the n^{th} point source

Q_n = emission rate of the n^{th} point source (g/s)

ρ_n = distance from the receptor to the n^{th} point source (m)

q_k = emission rate of the area source per unit area and unit time ($g/s\text{-}m^2$)

ρ = distance from the receptor to an infinitesimal area source (m)

θ = angle relative to polar coordinates centered on the receptor

ℓ = index identifying the wind speed class

m = index identifying the class of the Pasquill stability category

$\phi(k,\ell,m)$ = joint frequency function

z = height of receptor above ground level (m)

u_ℓ = representative wind speed (m/s)

h = effective stack height of source distribution, i.e., the average height of area source emissions in the k^{th} wind direction sector at radial distance ρ from the receptor (m)

L = the afternoon mixing height (m)

$T_{1/2}$ = assumed half life of pollutant hours (s)

a. Source-Receptor Relationship

Arbitrary location for each point source
Arbitrary location for each receptor
Area sources input as multiples of a user-defined unit size
Arbitrary release heights for point and area sources
Actual separation between each source-receptor pair used
Receptors are at ground level
No terrain differences between source/receptor

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
area integrations are done numerically one 22.5° sector at a time; sampling at discrete points defined by specific radial and angular intervals on a polar grid centered on the receptor
Day/night variations in emissions, same variation assumed for all sources

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Only Briggs neutral/unstable formula used for point sources
If stack height plus plume rise is greater than mixing height, ground level concentrations assumed equal to zero
Alternative to Briggs - input value of plume rise times wind speed for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
Wind speed corrected for release height based on power law variation exponents from DeMarrais[5]
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Climatological approach
Uniform distribution within each of 16 sectors
Averaging time = 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[2]
Day and night cases of neutral stability input separately
Dispersion coefficients taken from Turner[6]
Area sources - stability class is decreased by 1 category from input values (to account for urban effects)
Neutral dispersion coefficients are used for stable classes
No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half life

j. Physical Removal

Exponential decay, user-input half life
Always applies the same rate constant

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): assumes perfect reflection
Upper boundary (mixing height): no effect until dispersion coefficient equals 0.8 of the mixing height, uniform vertical mixing assumed beyond this point

m. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Mixing height is adjusted according to stability class:
- Class A - 1.5 times afternoon climatological value
- Classes B, C, and D(day) - equal to the afternoon climatological value
- Class D(night) - average of morning and afternoon climatological value
- Class E - morning climatological value

Emission rates: day-night allowed; all sources vary by same factor
Non-sequential (climatological) limited correlation

n. Validation/Calibration

Calibration option available (CDMQC)
Two validation studies documented in the user's guide
Some unpublished validation experience

o. Output

One month to one-year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen[1] procedure (typically 1 - 24 hr.) (CDMQC)
Assumes
(1) lognormal concentration distribution,
(2) power law dependence of median and maximum concentrations on averaging time
Arbitrary number and location of receptors
Individual point, area source culpability list for each receptor (CDMQC)
Point, area concentration rose for each receptor

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Useable for urban areas only
Area source emission densities must not vary rapidly from one area source to the next

A.4 GAUSSIAN-PLUME MULTIPLE SOURCE AIR QUALITY ALGORITHM (RAM)

Reference: Turner, D. B., and J. H. Novak, "User's Guide for RAM." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1978.

Abstract: RAM is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour. Both rural and urban versions are available.

Equations:

The area source contributions are determined using the narrow-plume hypothesis similar to applications by Gifford and Hanna[7]. Contribution. Contribution from a single upwind area source

$$\chi_A = \frac{q}{u} \int_{x_1}^{x_2} f \, dx \qquad \text{integral evaluated numerically}$$

x_1, x_2 = points of intersection of ray from receptor through area source in question

q = emission rate per unit area of the area source ($g/s\text{-}m^2$)

u = mean wind speed (m/s)

For stable conditions: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_2$

$$\chi_{point} = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z} g_1 g_2$$

For neutral or unstable conditions, $\sigma_z \leq 1.6L$: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_3$

$$\chi_{point} = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z} g_1 g_3$$

For neutral or unstable conditions, $\sigma_z > 1.6L$: $f = \frac{1}{L}$

$$\chi_{point} = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y} g_1$$

In which

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \left\{ \exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right] \right\}$$

a. Source-Receptor Relationship

Arbitrary location for point sources
Receptors may be
(1) arbitrarily located
(2) internally located near individual source maxima
(3) on a program-generated hexagonal grid to give good coverage to a user-specified portion of the region of interest
Receptors all at same height above (or at) ground
Flat terrain assumed
Unique stack height for each point source
User may specify up to three effective release heights for area sources, each assumed appropriate for a 5 m/sec wind speed. Value used for any given area source must be one of these three
Unique separation for each source-receptor pair

b. Emission Rate

Unique, constant emission rate for each point, area source
Area source treatment-
Narrow plume approximation
Area source used as input; not subdivided into uniform elements
Arbitrary emission heights input by user

Areas must be squares; side lengths = integer multiples of a basic unit
Effective emission height = that appropriate for 5 m/s wind
Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for contribution from area source with given effective release height

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8,9,10] plume rise formulas
Does not treat fumigations or downwash
If plume height exceeds mixing height, ground level concentration is assumed zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally by Turner[2] procedure, six classes used
Dispersion coefficients from McElroy and Pooler[3] (urban) or Turner[6] (rural). No further adjustments made for variations in surface roughness or transport time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally
Dispersion coefficients from McElroy and Pooler[3] (urban) or Turner[6] (rural). No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half-life

j. Physical Removal

Exponential decay, user-input half-life

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection
Neutral and unstable conditions
  Multiple reflections numerically accounted for by summation of series until σ_z = 1.6 times mixing height
  Uniform mixing assumed in vertical thereafter
Stable conditions: there is no upper boundary
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day
Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, wind direction, mixing height and other meteorological variables required for determination of stability class and plume rise

n. Validation/Calibration

No calibration option provided
Limited experience with validation or comparison with observed data

o. Output

Hourly and average (up to 24 hours) concentrations at each receptor
Limited individual source contribution list
Cumulative frequency distribution based on 24-hour averages and up to 1 year of data at a limited number of receptors

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat or gently rolling terrain

A.5 SINGLE SOURCE (CRSTER) MODEL

Reference: Environmental Protection Agency. "User's Manual for Single Source (CRSTER) Model." Publication No. EPA-450/2-77-013 (NTIS PB 271360). Office of Air Quality Planning and standards, Research Triangle Park, North Carolina 27711, July 1977.

Abstract: CRSTER is a steady state Gaussian plume technique applicable to both rural and urban areas in uneven terrain. The purpose of the technique is: (1) to determine the maximum concentrations, for certain averaging times between 1-hour and 24-hours, over a one year period due to a single point source of up to 19 stacks, (2) to determine the meteorological conditions which cause the maximum concentrations, and (3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight - to - midnight averages are determined for each 24-hour period.

Equations:

$$x = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z}\, g_1\, g_3 \qquad \text{for } \sigma_z \leq 1.6L$$

$$x = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y}\, g_1 \qquad \text{for } \sigma_z > 1.6L$$

$x = 0$ (stability class 7)

L = mixing height (m)

H = (stack height + plume rise)-(difference in elevation between receptor and base of stack)

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \exp\left\{\left[-\frac{1}{2}\,\frac{2nL-H}{\sigma_z}^2\right] + \exp\left[-\frac{1}{2}\,\frac{2nL+H}{\sigma_z}^2\right]\right\}$$

a. Source-Receptor Relationship

Up to 19 point sources, no area sources
All point sources assumed at the same location
Unique stack height for each source
Receptor locations restricted to 36 azimuths (every 10°) and 5 user-specified radial distances
Unique topographic elevation for each receptor; must be below top of stack

b. Emission Rate

Unique average emission rate for each source
Monthly variation in emission rate allowed

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8, 9, 10] final plume rise formulas
Does not treat fumigation or downwash
If plume height exceeds mixing height, concentrations further downwind assumed equal to zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, exponents from DeMarrais[5], different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
7 stability classes used; Turner Class 7: extremely stable, elevated plume assumed not to touch the ground
Dispersion coefficients from Turner; no further adjustments made for variations in surface roughness, transport or averaging time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
7 stability classes
Dispersion coefficients from Turner; no further adjustments made

i. Chemistry/Reaction Mechanism

Not treated

j. Physical Removal

Not treated

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection at the same height as the receptor
Upper boundary: perfect reflection
Multiple reflections handled by summation of series until
σ_z = 1.6 x mixing height
Uniform vertical distribution thereafter
Mixing height is constant and follows topographic variations:
Taken from base of stack for determining whether plume punches through
Taken from receptor elevation for determining vertical concentration distribution
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day. Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise.

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, direction, mixing height and other meteorological variables required for determination of stability class and plume rise
Monthly emission variation allows limited emission - meteorology correlation

n. Validation/Calibration

No calibration option provided
Comparison with observations around at least 5 separate power plants have been made

o. Output

Highest and second highest concentrations for the year at each receptor for averaging times of 1, 3, and 24-hours, plus a user-selected averaging time which may be 2, 4, 6, 8, or 12 hours
Annual arithmetic average at each receptor
For each day, the highest 1-hour and 24-hour concentrations over the receptor field
Hourly concentrations for each receptor on magnetic tape

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Not applicable to area and line sources
Use care when applying to low-level sources

A.6 TEXAS CLIMATOLOGICAL MODEL

References: Porter, R. A. and Christiansen, J. H.. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976.

Christiansen, J. H. and Porter, R. A.. Users Guide to the Texas Climatological Model, Texas Air Control Board, Austin Texas, May, 1976.

Abstract: The TCM is a climatological model that predicts long-term arithmetic mean concentrations of nonreactive pollutants from point sources and area sources.

Equations:

Area sources are handled by an algorithm proposed by Gifford and Hanna[7]. The concentration due to area sources is given by

$$\chi_A = FQ/U$$

where χ_A = concentration ($\mu g/m^3$)

Q = area source emission rate in the vicinity of the receptor ($\mu g/s\text{-}m^2$)

U = mean ground-level wind speed (m/s)

F = a dimensionless constant

Gifford and Hanna have suggested a value of F = 50 for SO_2 and 225 for total suspended particulate (TSP). The area emission rate, Q, is determined by averaging the emissions in the area source square containing the receptor and in the neighboring squares. The extent of the region around each receptor to use for emission rate averaging is an input parameter.

The TCM uses steady-state Gaussian plume point source logic, with the crosswind distribution averaged across 22.5° azimuthal sectors. The only meteorological input required for area source calculations is the mean wind speed, but the point source calculations require a meteorological joint frequency function with sixteen 22.5° wind sectors, six wind speed classes (0-3, 4-6, 7-10, 11-16, 17-21, and > 21 knots), and six stability classes (Turner classes A, B, C, D (day), D (night), and E plus F).

The basic equation is:

$$\chi = Q_i \sum_{m=1}^{6} (K(x,H,m)\phi(k,m)/U_m) \cdot (\text{decay term})$$

where $K(x,H,m) = (32 \times 10^6/[(2\pi)^{3/2} \times \sigma_z]) \exp(-H_i^2/2\sigma_z^2)$

(K is precalculated for 20 distances, 9 effective source heights, and six stability classes)

U_m is a wind speed characteristic of an entire stability class, and is computed in the model by the equation:

$$U_m = \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)\right] \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)/U_\ell\right]^{-1}$$

with χ = concentration, $\mu g/m^3$

k = the wind sector index appropriate to source i at the receptor

ℓ = wind speed class index

m = stability class index

ϕ = meteorological joint frequency function

Q_i = emission rate of source i, g/s

H_i = effective height of source i, m

σ_z = standard deviation of vertical Gaussian concentration distribution, m

$T_{1/2}$ = half-life for first-order pollutand decay, s

U_ℓ = central wind speed of class ℓ, m/s

x = downwind distance, m

a. Source-Receptor Relationship

Arbitrary location for each point source
Unlimited number of sources
Arbitrary location and square grid width for each area source
The model will allocate area sources into a uniform square grid
Receptor location is arbitrary grid (max. 50 x 50)
Release heights for point sources
The area source algorithm (Gifford-Hanna) does not consider height of release
Receptors are at ground level
No terrain difference between sources and receptors

b. Emission Rate

All sources have a single average emission rate for the averaging time period (i.e., month, season, year)

c. Chemical Composition

One, two, or three inert pollutants are treated simultaneously

d. Plume Behavior

Plume rise calculated according to Briggs[9] neutral/unstable equation
Effective stack heights less than 10 meters are considered 10 meters
Effective stack heights greater than 300 meters are considered 300 meters
No plume rise for area sources
Down-wash and fumigation not considered

e. Horizontal Wind Field

Climatological approach
16 wind directions
Mean wind speed calculated for each stability class from the joint frequency function of stability, wind direction, and wind speed
Wind speed corrected for physical stack height (same as CDM)

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Assumed to be uniform within each 22.5 degree sector (same as CDM)

h. Vertical Dispersion

Gaussian plume
6 stability classes (Pasquill-Gifford-Turner) A, B, C, D-Day, D-Night, E and F
No provision for variation in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay according to user input half-life (same as CDM)

j. Physical Removal

Same as i above

k. Background

Background may be entered by calibration coefficient for each pollutant

l. Boundary Conditions

Perfect reflection assumed at ground
Mixing height not considered

m. Emission and Meteorological Correlation

Emissions not varied

n. Validation/Correlation

Model is self-calibrating with input of field receptor observations
High correlation achieved for areas dominated by point sources
Poorer correlations have been shown where area sources are dominant

o. Output

Arithmetic mean concentration for the averaging time of the climatological input and emission data (one month to one year)
Any combination of the following outputs are available:
(1) Listing of concentration for an arbitrarily spaced square grid of up to 50 by 50 elements
(2) A print plot of the grid concentrations
(3) Punched card output for isopleth maping (same as CDM)
(4) A listing of the five high contributors to the concentration (by % concentration) at each grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat terrain, relatively constant emissions
Use not recommended where area sources dominate

A.7 TEXAS EPISODIC MODEL (TEM)

References: Porter, R. A. and Christiansen, J. H. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976.

Christiansen, J. H. Users Guide to the Texas Episodic Model, Texas Air Control Board, May, 1976.

Abstract: The Texas Episodic Model TEM is a short-term (10 minute to 24 hour averaging time) Gaussian Plume Model for prediction of concentrations of nonreactive pollutants due to up to 300 elevated point sources and up to 200 area sources. Concentrations are calculated for 1 to 24 scenarios of meteorological conditions, averaging time, and mixing height

Equations:

The area source algorithm is due to Gifford and Hanna.[7] Each area source square is affected by its own diffuse emissions and those in the N area source squares directly upwind of it:

$$\chi = \left(\frac{2}{\pi}\right)^{1/2} \frac{(\Delta x/2)^{1-b}}{U_o\, a(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b}\right] \right\}$$

with Δx = length of side of area source grid squares (m)

U_o = surface wind speed (m/s)

Q_o = area emission rate of square containing the receptor ($\mu g/s\text{-}m^2$)

Q_i = area emission rates of the upwind area sources ($\mu g/s\text{-}m^2$)

a,b = stability and downwind distance-dependent parameters from the equation $\sigma_z = ax^b$

The TEM employs steady-state bivariate Gaussian plume point source logic. The concentration due to an elevated point source is given by

$$\chi = \frac{10^6 Q}{\pi \sigma_y \sigma_z U} \exp(-y^2/2\sigma_y^2) \exp(-H^2/2\sigma_z^2) \exp(-.692x/UT_{1/2})$$

where χ = concentration ($\mu g/m^3$)

Q = emission rate (g/s)

U = wind speed at physical source height (m/s)

H = effective source height (m)

x = downwind distance (m)

y = crosswind distance (m)

$T_{1/2}$ = first-order pollutant decay half-life (s)

σ_y, σ_z = the standard deviations of the plume concentration distribution,

$$\sigma_z = ax^b$$

$$\sigma_y = cx^d$$

with stability and downwind distance-dependent coefficients a, b, c, and d from Busse and Zimmerman[11] and Turner[6]. The wind speed U is the surface wind speed adjusted to the physical source height. Let K_y and K_z be defined by

$$K_y = \frac{1000}{\sigma_y} \exp(-y^2/2\sigma_y^2),$$

$$K_z = \frac{1000}{\pi\sigma_z} \exp(-H^2/2\sigma_z^2)$$

Then, $$\chi = \frac{K_y K_z Q}{U} \text{ (decay term)}$$

K_y was calculated for each of the 1120 combinations of twenty downwind distances from 2 to 60 km, eight crosswind angles ($Tan^{-1}y/x$) from 0° to 7°, with δ varying from 1° to 5° depending on stability, and seven stability classes. For total vertical mixing below a mixing height of L meters,

$$\chi = \frac{10^6 Q}{\sqrt{2\pi}\ \sigma_y LU} \exp\ (-y^2/2\sigma_y^2)$$

This can be represented in the equation $\chi = \frac{K_y K_z Q}{u}$ (decay term)

by setting $K_z = 398L$

a. Source-Receptor Relationship

Up to 300 arbitrarily located point sources
Up to 200 arbitrarily located area sources
A uniform square receptor grid of arbitrary spacing with up to 50 by 50 rows or columns
Terrain assumed flat
Unique release height for each source
All receptors at ground level

b. Emission Rate

Unique emission rate for each source

c. Chemical Composition

One, two, or three inert pollutants treat simultaneously

d. Plume Behavior

Plume rise according to one of six equations from Briggs selected according to stability and distance from source. Effective stack heights less than 10 meters are considered 10 meters. Effective stack heights greater than 2000 meters are considered 2000 m.
Mixing height penetration factor (P) is a user input. If effective source height (h) is greater than P times the mixing height the plume escapes. Otherwise the .47L mixing scheme from Turner[6] is used.
Does not treat downwash or fumigation

e. Horizontal Wind Field

User supplied stability, wind speed, and direction for the averaging time period (10 minutes to 3 hours) or for each 3 hour period to build a 24-hour day.
Power law variation of wind speed with release height (same as CDM).
Steady state wind for each scenario

f. Vertical Wind Speed

Equal to zero

g. Horizontal Dispersion

Semi-empirical Gaussian plume
User supplied stability class for each scenario (Pasquill-Gifford-Turner)
Turner[6] dispersion coefficients
No adjustment for surface roughness

h. Vertical Dispersion

Semi-empirical Gaussian plume
User supplied stability classes (Pasquill-Gifford-Turner) for each scenario
Turner[6] dispersion coefficients
No adjustment for surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay with user supplied half-life

j. Physical Removal

Same as i above

k. Background

May be input with calibration factor

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: reflection from top of mixed layer by the .47L scheme of Turner[6] except as described in d above

m. Emission/Meteorological Correlation

User supplied values of wind speed, wind direction, stability class, mixing height, ambient temperature for each scenario up to 24 scenarios

n. Validation/Calibration

Calibration by user supplied coefficients (A, B) so that
$X_{cal} = A + BX_{predicted}$
Limited experience with validation or comparison with observed data

o. Output

Concentration mean for each receptor grid point for averaging times of:
10 minutes
30 minutes
1 hour
3 hours
24 hours (based on eight 3-hour scenarios)
output is available for from 1 to 24 scenarios in the following formats:
listing
print plot
punched cards for isopleth maps
culpability list of the high five contributors to the concentration at each receptor grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Relatively uncomplicated terrain
Reliability is not established for cases where area sources are dominant

A.8 References

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